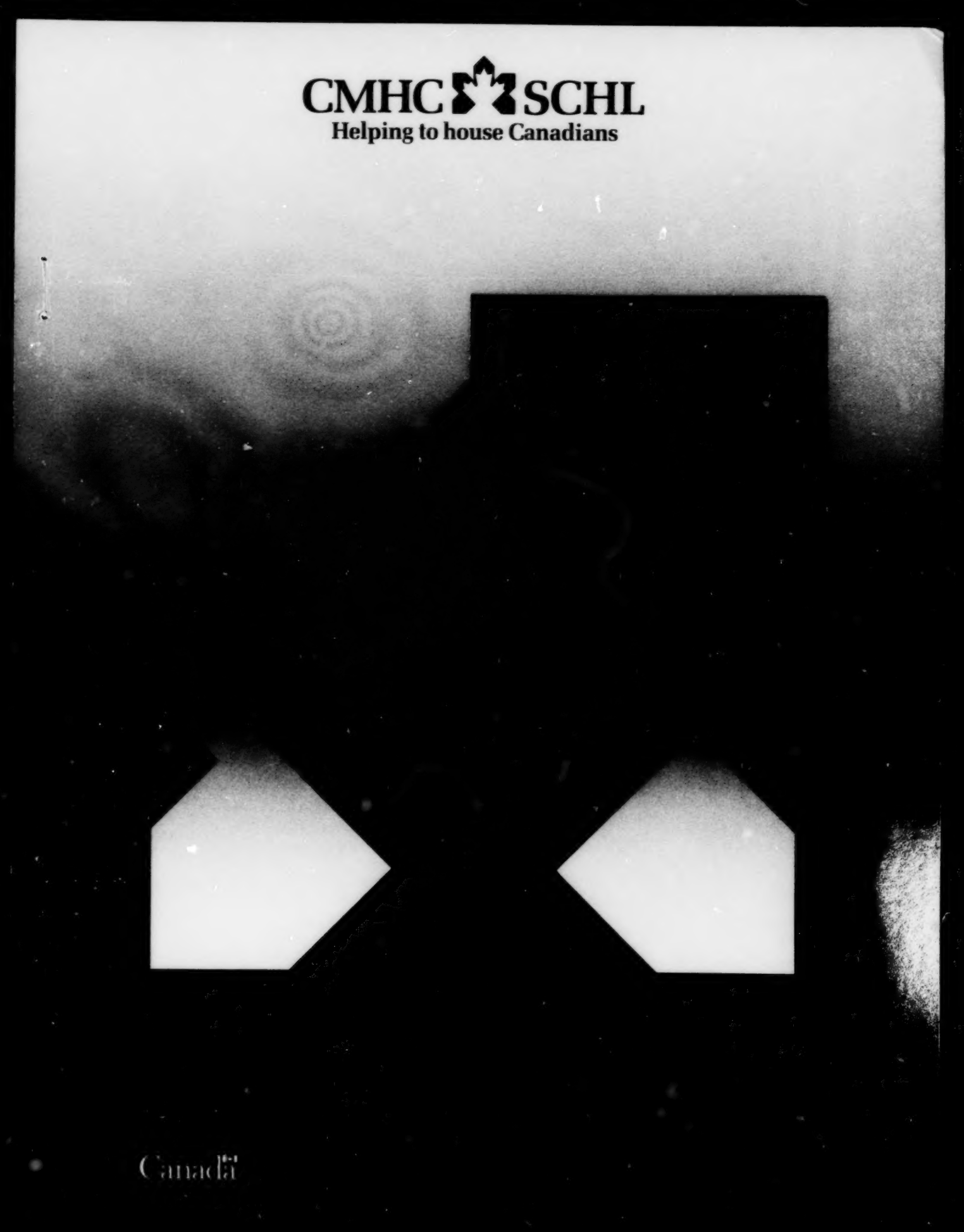
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HOUSING TECHNOLOGY INCENTIVE PROGRAM

DEVELOPMENT AND EVALUATION OF A MONOCOQUE ROOF SYSTEM:

FINAL REPORT

PREPARED BY: SYLVAPRO INC.

Under the responsibility of:
Raymond Couture

June 10, 1991

DEVELOPMENT OF A MONOCOQUE ROOF SYSTEM

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1. INTRODUCTION

1.1 The basic idea

This represents the conclusion on the development and evaluation of a new Monocoque Roof System.

A Monocoque light and rigid roof panel composed of O.S.B. wafer board sheets where all especialy designed jointing between every components are "welded" with polyester resin.

The triangular and longitudinal strips sloped on 45° jointed longitudinaly into a specially designed technique, create such a continuous "weld" that it results in a very strong panel that resists remarquably well to vibration, flexion, shear and torsion, making same most easy for assembling one panel into another.

Considering such a rigidity in all aspects will no doubt make a house shell that will resist to any hasards such as ground movements, extreme winds and hurricanes.

1.2 The potential benefits to the housing industry

The conventional method to build a roof has not changed for many decades, the most common way being the use of wood trusses and intermediate multiple wood bracing which is time consuming and expensive in labour. Furthermore, it is difficult to accomplish a well insulated and air tight roof which is the most important part of the house.

.../2

When a customer wants a cathedral ceiling, it becomes even more expensive to build.

Our "monocoque" roof panels are a ready made cathedral ceiling at no extra cost (the extra cost will be to provide a flat ceiling and it can be economically made from inside by a simple drop ceiling technique).

The fast installation of our "monocoque" roof system (a couple of hours) will reduce the construction cost substantially.

The housing industry will also benefit from many other advantages such as time saving, and quaranteed quality under any climatic condition.

2. METHOD

2.1 Phase I

Under this first phase, the overall design was reviewed in order to optimize the control of mecanic jointing of components "welds" in manufacturing process as well as testing techniques in order to simulate as much as possible the normal conditions.

Full size (16' long) panels were made for testing purposes.

.../3

2.2 Phase II

Under this second phase, the prototypes were delivered to McGill laboratory and complete testing were executed under the supervision of Prof. Saeed Mirza.
Photographs of the most important aspects of testing have been taken. (Copies are inclosed within McGill report). A complete recording of all details of the testing were registered to form part of the McGill final report.

3. RESULTS

3.1 Conclusion

The execution of the present research program has given us the opportunity to explore, experiment and test the different physical properties and other aspects of this "monocoque" roof system and prove its pertinence, its top quality, convenient aspects and its competitive price will no doubt make it a very popular construction component.

RÉSUMÉ À L'INTENTION DE LA DIRECTION

---

1. INTRODUCTION

1.1 L'idée de base

Ce texte présente les résultats de la mise au point et de l'évaluation d'un nouveau toit monocoque.

Ce toit monocoque à la fois léger et rigide se compose de panneaux de copeaux orientés dont tous les joints, spécialement conçus à cette fin, sont «soudés» à l'aide d'une résine de polyester.

Les bandes triangulaires et longitudinales, suivant une pente de 45° et jointoyées longitudinalement selon une technique spéciale, forment une «soudure» continue qui permet à l'ensemble de résister remarquablement bien aux vibrations, aux flexions, aux cisaillements et aux torsions. En outre, les différents panneaux sont très faciles à assembler.

Cette rigidité d'ensemble laisse entrevoir que le gros oeuvre pourrait soutenir des pressions comme les secousses sismiques, les vents violents et les ouragans.

1.2 Avantages potentiels pour l'industrie du logement

La méthode classique de construction d'un toit est restée inchangée depuis des décennies. On utilise le plus souvent des fermes en bois et des entretoises intermédiaires multiples, également en bois, dont la mise en oeuvre exige beaucoup de temps et d'efforts, donc d'argent. De plus, il est difficile, par cette méthode, de bien isoler le toit et de le rendre parfaitement étanche à l'air, lui qui constitue le plus important élément d'une maison.

Quand un client désire un plafond cathédrale, la méthode traditionnelle entraîne des coûts encore plus onéreux.

Les panneaux de toit monocoques forment déjà un plafond cathédrale sans occasionner de frais additionnels (il en coûterait plus seulement si l'on désirait avoir un plafond plat; il s'agirait alors de l'aménager de l'intérieur, à peu de frais, en ayant recours à la technique simple du faux plafond).

La rapidité d'installation du toit monocoque (quelques heures) contribuera à diminuer considérablement les coûts de construction.

L'industrie du logement bénéficiera aussi de nombreux autres avantages comme l'économie de temps et la garantie de qualité dans n'importe quelle condition climatique.

2. MÉTHODE

2.1 Phase I

Au cours de la première phase, la conception globale a été revue afin d'optimiser le contrôle du jointoiement mécanique des «soudures» en cours de fabrication de même que les techniques d'essai pour simuler le mieux possible les conditions normales.

Les essais ont été menés sur des panneaux entiers de 16 pi.

2.2 Phase II

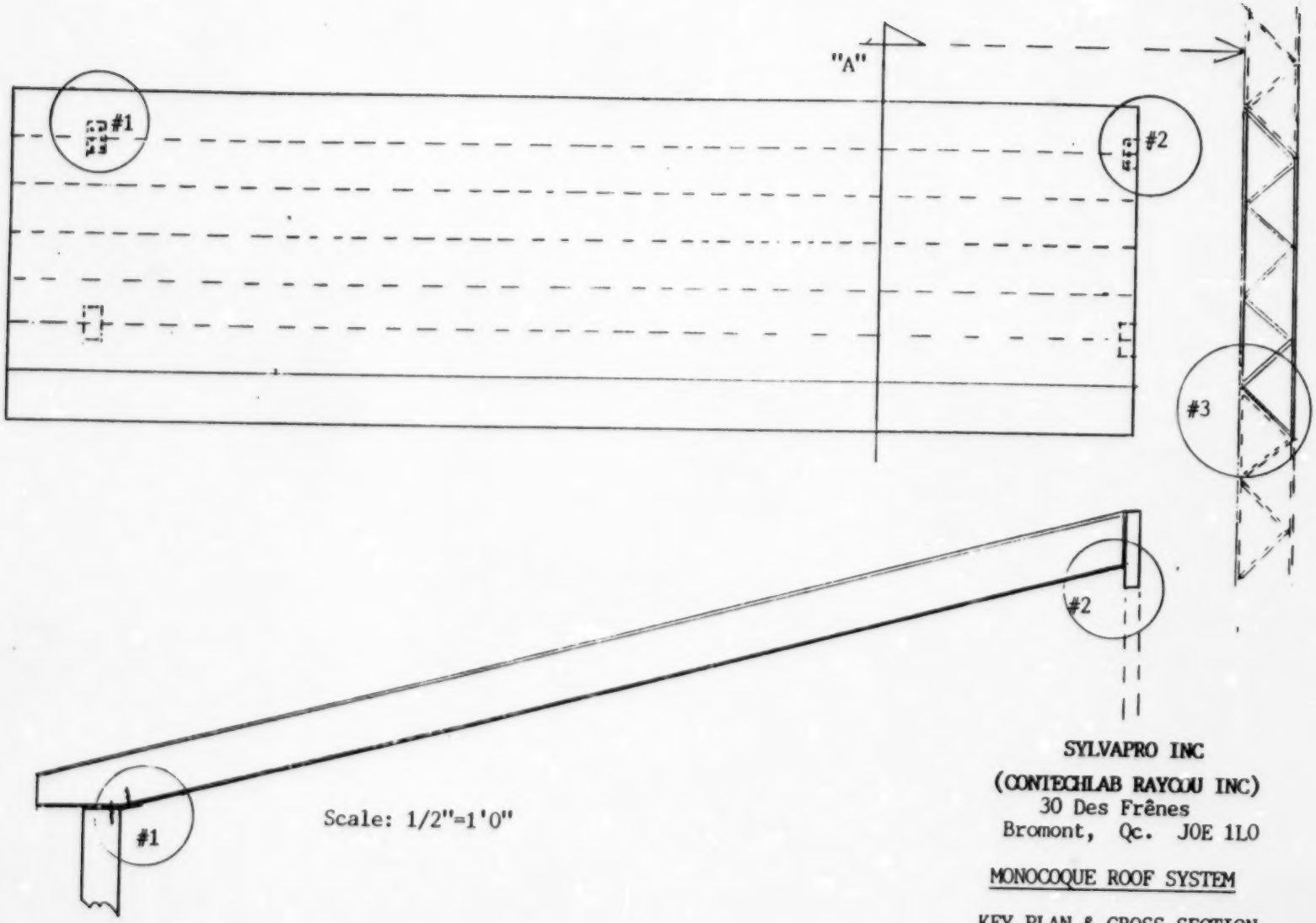
Lors de cette deuxième phase, les prototypes ont été expédiés au laboratoire de l'université McGill pour procéder à des essais complets sous la supervision du professeur Saeed Mirza.

Les aspects les plus importants des essais ont été photographiés. (Des photos ont été jointes au rapport du laboratoire.) Tous les détails des essais ont été enregistrés et forment une partie du rapport final de l'université McGill.

3. RÉSULTATS

3.1 Conclusion

Ce programme de recherche nous a donné l'occasion d'explorer, d'expérimenter et de mettre à l'essai les différentes propriétés physiques ainsi que d'autres aspects de ce toit monocoque et de prouver sa pertinence, sa haute qualité et sa commodité. Son prix concurrentiel en fera certainement un élément du bâtiment des plus populaires.



Scale: 1/2"=1'0"

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Bromont, Qc. J0E 1L0

MONOCOQUE ROOF SYSTEM

KEY PLAN & CROSS SECTION

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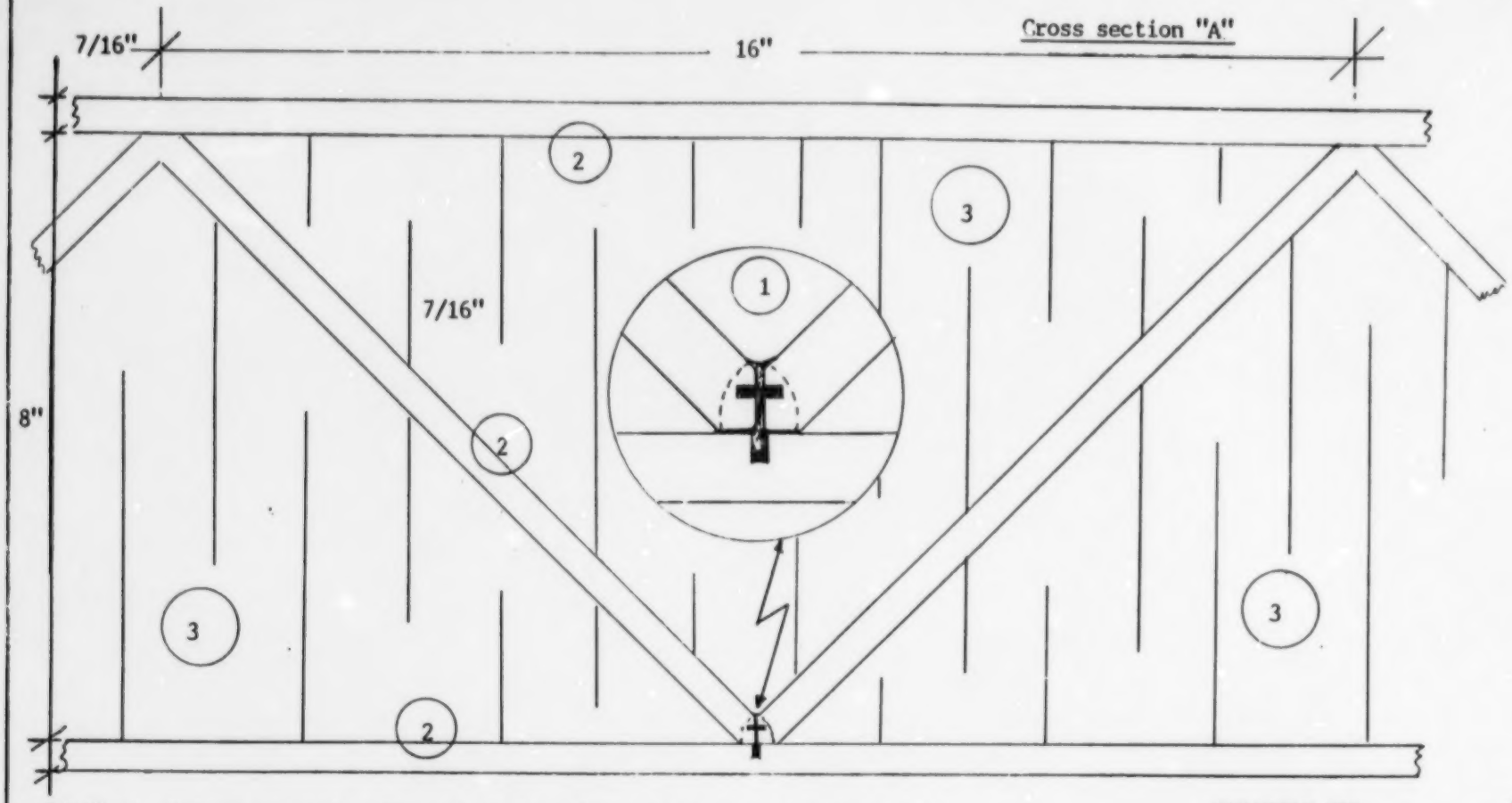
Drawing #1



1. Polyester resin (Poured in place)
2. O.S.B. Wafer Board
3. Pre-mold, expanded polystirene
   Tight fitted (@ R-4 per inch)

Scale: Full & Half Full

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MONOCOQUE ROOF SYSTEM

CONSTRUCTION DETAIL

& "WELDING" TECHNIQUE

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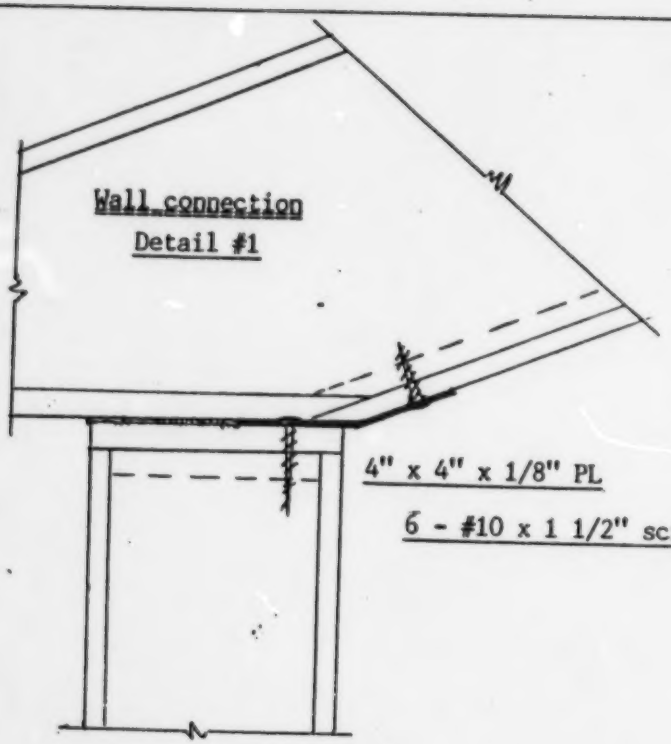
Drawing #2



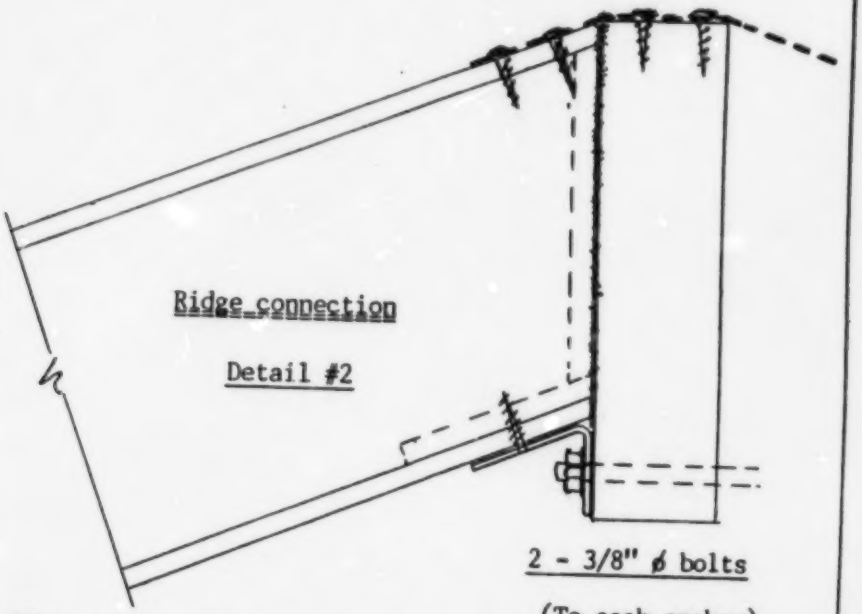
Wall connection

Detail #1

4" x 4" x 1/8" PL

6 - #10 x 1 1/2" screws

2- 20 G. Galv x 1 1/2" straps each pannel



Ridge connection

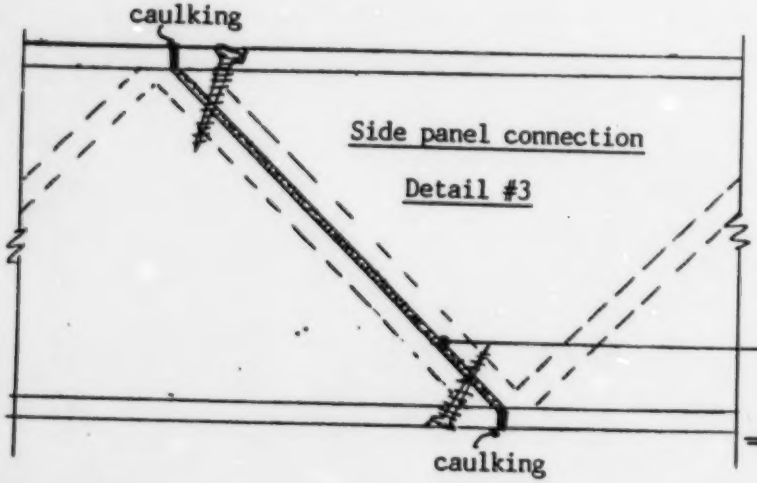
Detail #2

2 - 3/8" ø bolts

(To each anchor)

3" x 3" L x 6" x 1/8" @ 2'0" O.C.

3 - #10 x 1 1/2" screws



Side panel connection

Detail #3

#10 x 2" screws @ 12" c.c.

Wrethane foam gasket

Scale: 3"=1'0"

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MONOCOQUE ROOF SYSTEM

CONNECTION DETAILS

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Drawing #3

PRELIMINARY REPORT
ON
AN EXPERIMENTAL STUDY
OF THE BEHAVIOUR
OF
PREFABRICATED WAFERBOARD ROOF STRUCTURE

M. Saeed Mirza
Department of Civil Engineering
and Applied Mechanics,
Montreal, Quebec

Montreal

May 30, 1991

Summary

This report presents the results of the structural behaviour of a prefabricated waferboard roof structure of dimensions $16' \times 48" \times 8"$ subjected to gradually increasing applied loads until failure. The experimental results show that the structure has the following strength resistance (including dead and live loads) for selected values of centre span deflection:

For Centre Span Deflection	Equivalent Uniformly Load Distribution (lb/ft^2)
1/360	48.4
1/240	80.9
At Failure	138.7

The average fundamental natural frequency of the specimen is 11.4 Hz.

The mode of failure of the waferboard specimen was very distinct, with one large joint breaking open at the connection between the exterior web and the top flange. At the same time, the other exterior web failed due to buckling in a folding mode with a major crack along the folded edge of the web.

This report presents the test results of only one specimen. Therefore, it is recommended that more tests be undertaken with varying span lengths and widths to determine the overall structural behaviour of the prefabricated waferboard roof structure.

SECTION 1

DYNAMIC LOAD TESTS

Set-Up for the Dynamic Test

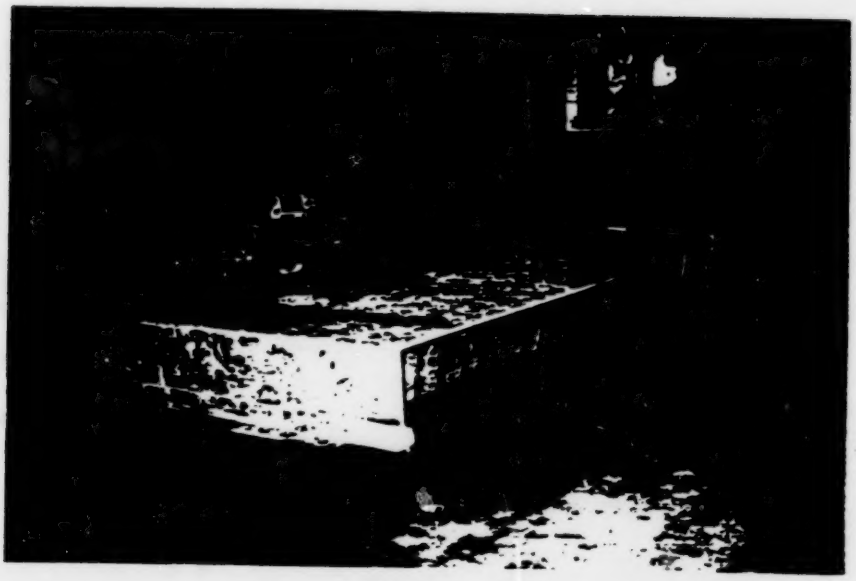
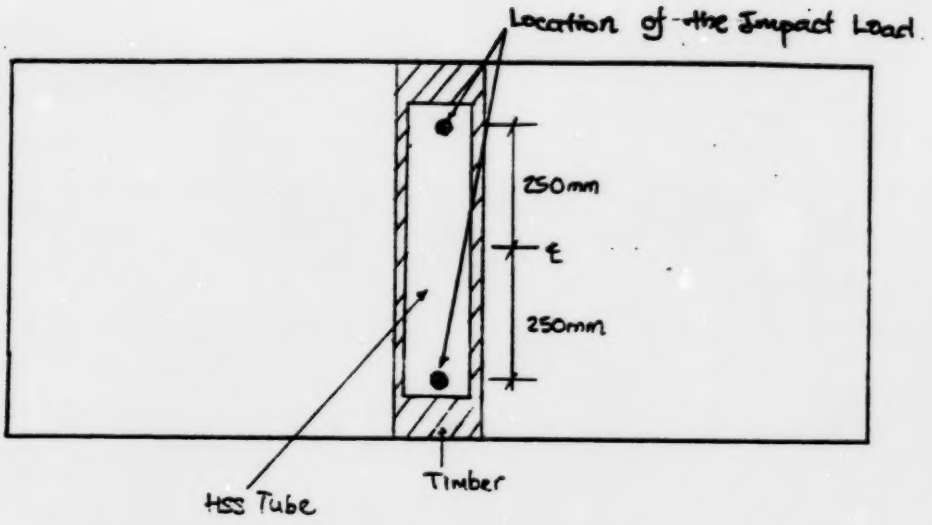


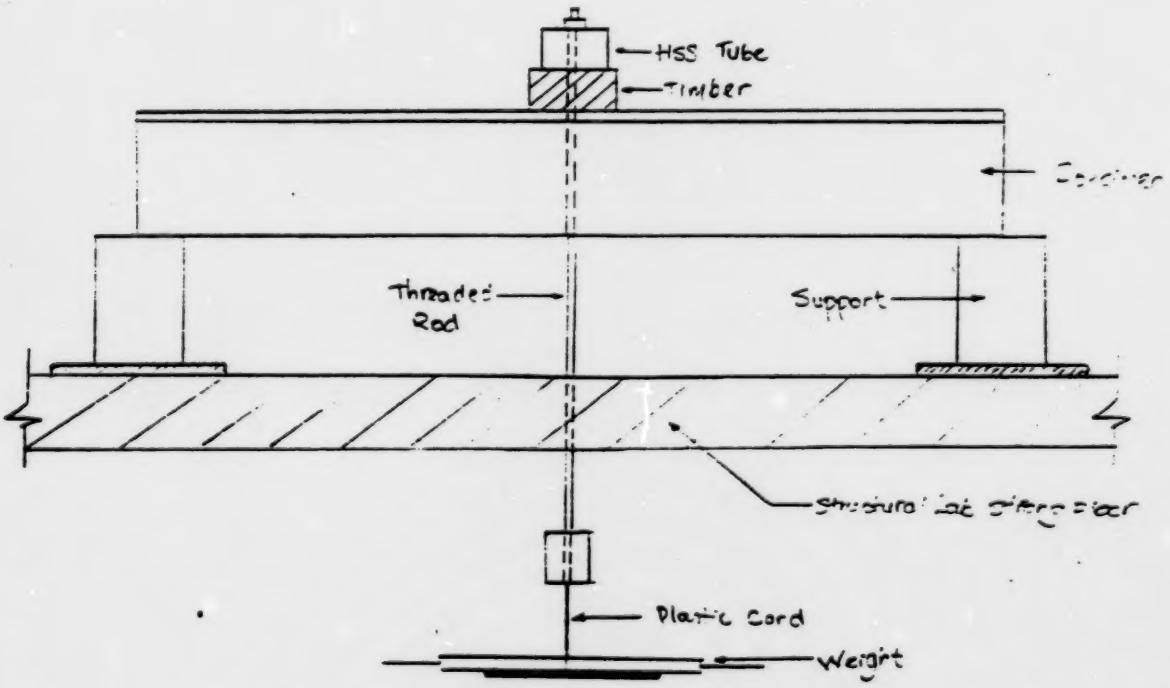
Figure 1.1

Test Procedure

1. The supports are connected to the strong floor to prevent any rotation during the loading process.
2. A 400 lb weight was applied at the centre of the span through a set-up which allowed the weight to be placed underneath the strong floor (Figures 1.1 and 1.2). The load was suspended using a plastic cord.
3. An oscilloscope was used to record the vertical deflection at midspan at a given instance.
4. The load at midspan was released suddenly by cutting the plastic cord.
5. A polaroid camera was used to record the variation of the vertical deflection with time.
6. The process was repeated one more time on each specimen to obtain two traces of the deflection variation with time.



Plan View



Side View

Figure 1.2

Results

1. The frequency of the specimen was calculated as:

$$\text{Frequency of the Roof} = \frac{\text{Number of Cycles}}{\text{Time Duration}}$$

2. For each case, two photographs of the deflection-time, taken using a polaroid camera, are presented. These deflection- time traces are used to calculate the fundamental natural frequency of vibration of the specimen (see Table 1.1). The average experimental fundamental frequency of vibration of the specimen is 11.4 Hz.

Table 1.1 Prefabricated Waferboard Roof Structure

Location of Applied Load (Figure 2)	Average Frequency of Vibration (Figure 2)
Centre Span	11.4 Hz.

Specimen Stiffness, K

The period of vibration, T, is given by the equation

$$T = \frac{2\pi}{\omega} = 2\pi\sqrt{\frac{W}{Kg}}$$

where ω represents the circular natural frequency, W is the load on the specimen, K is the beam stiffness at midspan due to the a concentrated load at midspan and g is the acceleration due to gravity. Also,

$$T = \frac{1}{f} = 2\pi\sqrt{\frac{W}{Kg}}$$

where f is the fundamental natural frequency of vibration. The value of stiffness of the staircase is calculated as:

$$K = \frac{4\pi^2 f^2 W}{g}$$

where $g = 32\ ft/sec^2$.The values of the self-weight plus the loading instruments on the staircases are summarized in Table 1.2.

Table 1.2 The Specimen's Self-Weight

Specimen	Weight (lb)
16 ft × 4 ft Roof Structure	516.5

The weight of the following items was included in the above calculation:

a. Threaded rod 20 lb
b. L-Shape steel beam 61.5 lb

The value of the stiffness of the specimen along with the values of the fundamental natural frequency of vibration is presented in Table 1.3.

Table 1.3 Summary of Values of Natural Frequencies and Stiffnesses of the Specimens.

Specimen	Natural Frequency (Hz)	Stiffness, K (Kips/ft)
16 ft × 4 ft Roof Structure	11.4	82.3

SECTION 2

ULTIMATE STATIC LOAD TESTS

Experimental Procedure

1. The test specimen was placed on supports providing simply supported end conditions.
2. The supports were attached to the strong floor by metal plates, threaded rods and nuts to prevent any movement during the tests.
3. Three loading points were used to transfer the applied load from the hydraulic jacks to the specimen (see Figures 2.1 and 2.2).
4. Five dial gauges were used to measure the vertical deflection of the specimen. The locations of the dial gauges is shown in Figure 2.3.
5. Dial gauges 1,3,5 were used to measure the vertical deflections of the specimen at the loading locations of the specimen, while dial gauges 2 and 4 were used to determine any torsional movement during the loading process.
6. The measured values of the loads and the deflections were recorded at the end of each load interval.
7. The specimen was gradually loaded until its failure in flexural tension.
8. The location and the propagation of the cracks and any other distress were recorded.

Test Set-Up for the Static Load Test

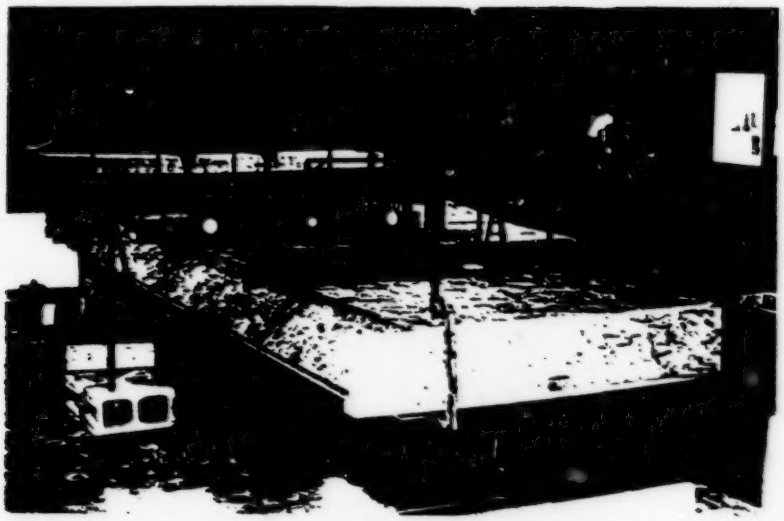


Figure 2.1

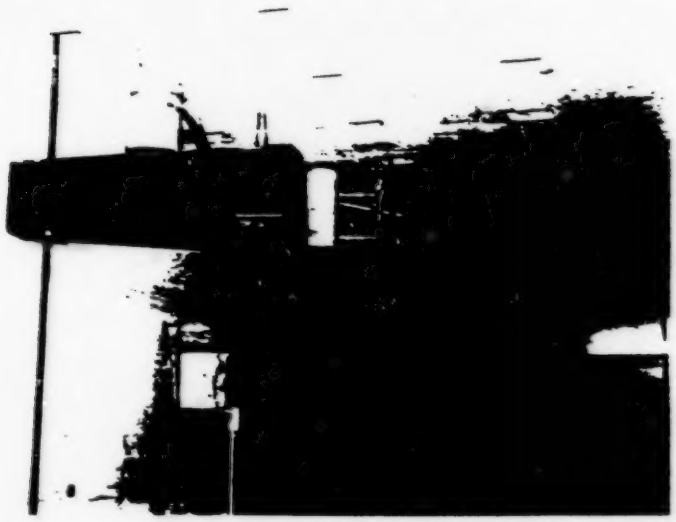


Figure 2.2

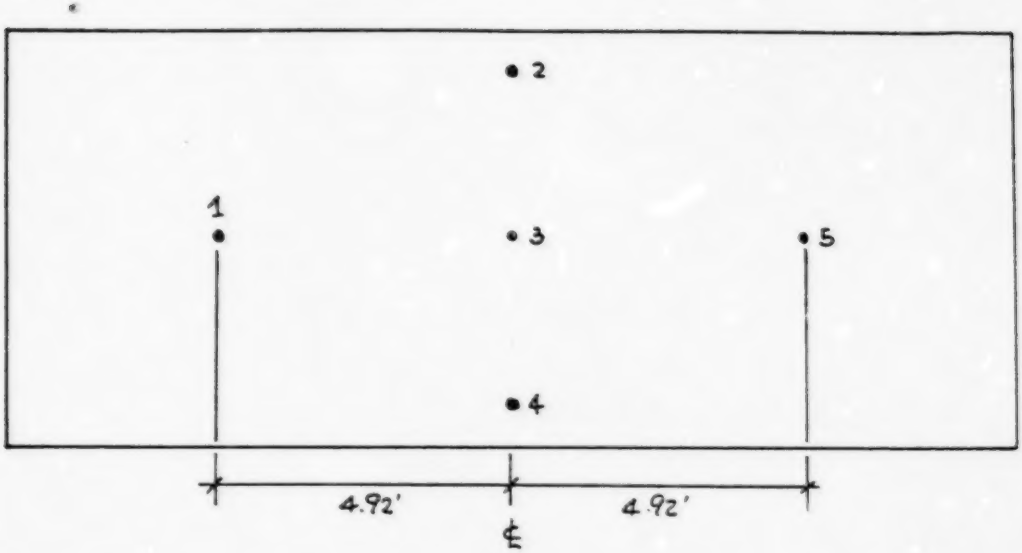


Figure 2.3 Location of Dial gauges

Piston Friction Force

In order to determine the friction force exerted by the hydraulic jack piston. the following method was used:

1. The hydraulic jack pressure was released down to zero.
2. It was ensured that the top piston surface of the hydraulic jack was not in contact with the strong floor.
3. The pressure was applied to the hydraulic jack, to determine the value of the pressure required to move the piston freely (i.e. not in contact with the strong floor surface).

The above method showed that the hydraulic jack had a friction pressure of 18.75 psi.

$$\Delta P = -18.75 psi$$

Evaluation of Equivalent Uniformly Distributed Load

1. Table 2.1 lists the weights of the various instruments used in the ultimate load test.
2. The weights of the various loading instruments were considered in calculating the maximum flexural moment at the centre of the span.
3. The piston friction force of the hydraulic jack was 18.75 psi. This value of the piston friction force was subtracted from each measured hydraulic pressure reading.
4. The maximum bending moment at the centre of the span was calculated.
   The equivalent uniformly distributed load (lb/ft) was calculated as follows:

$$\frac{Wl^2}{8} = M_{max\ at\ centre}$$
$$W = \frac{8M_{max\ at\ centre}}{l^2}$$

5. Equivalent distributed load (lb/ft^2) was obtained as follows:

$$W_{area} = \frac{W}{b} \qquad \text{where } b \text{ is the width of the specimen}$$

6. The variation of the equivalent distributed load (lb/ft^2) versus the centre span vertical deflection was plotted (see Figure 2.5).
7. Table 2.2 summarizes the values of the equivalent distributed load on the specimen for its ultimate load.

Table 2.1 Weights of the Instruments

1. Hydraulic jack	46 lb
2. 4" x 4" HSS section for positioning the hydraulic jack jack and the load cell in vertical position	38 lb
3. Loading arm for dial gauge #1	61.5 lb
4. Loading arm for dial gauge #3	61.5 lb
5. Loading arm for dial gauge #5	105 lb
6. Threaded rod	10 lb

Dead Load Applied on the Specimen

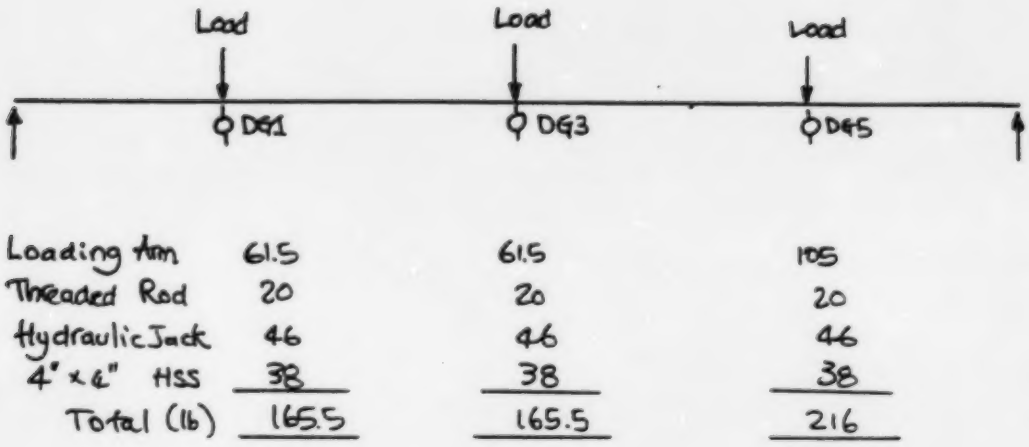


Figure 2.4

Table 2.2 Summary of the Equivalent Uniformly Distributed Loads for the Prefabricated Waferboard Roof Structure for Specified Midspan Deflections.

Prefabricated Waferboard Roof Structure Dimensions: 16 $ft \times 4\ ft$	
Vertical Deflection (in)	Equivalent Uniformly Distributed Load (lb/ft)
$\delta = \frac{L}{360} = 0.53$	48.4
$\delta = \frac{L}{240} = 0.80$	80.9
At Failure, $\delta = 3.0$	138.7

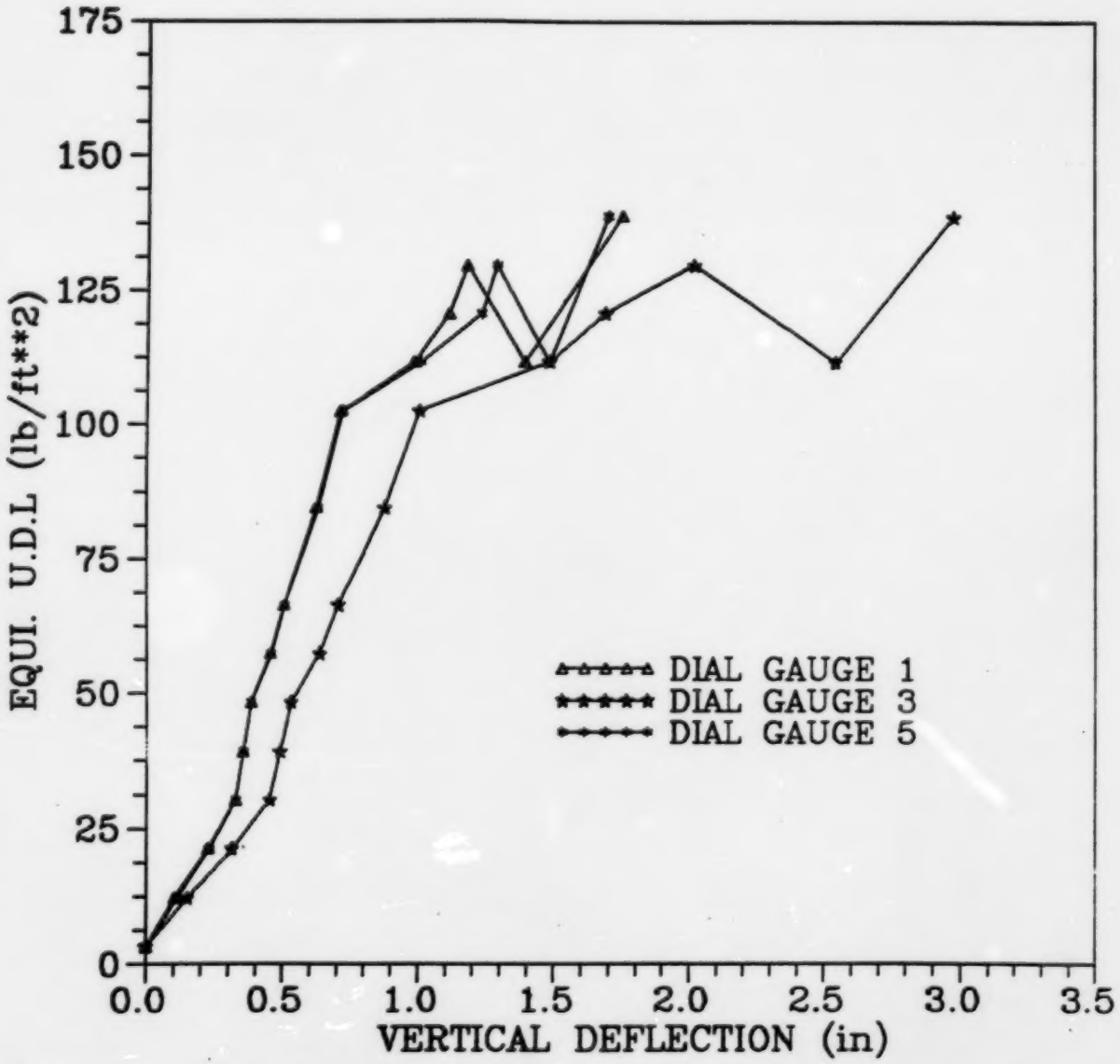


Figure 2.5 Load-Deflection Curve for the Prefabricated Waferboard Roof Structure

SECTION 3

MODES OF FAILURE

Mode of Failure

1. The applied load was increased gradually in increments of 165 lb at each loading point until failure.
2. First noticeable joint opening failure was observed at the joint connection between the external web and the top flange at an applied load value (in terms of equivalent uniformly distributed load) of 103 lb/ft^2 (see Figure3.1).
3. As the applied load was increased gradually to 130 lb/ft^2, the midspan deflection increased suddenly causing the previously formed joint opening to become wider. The strength of the specimen dropped to 112 lb/ft^2 immediately upon the widening of this crack.
4. Finally, the specimen failed at an ultimate load of 139 lb/ft^2 with the joint in item 3 opening even wider and more extended cracking in the web near the midspan, which had buckled earlier (see Figures 3.2 and 3.3).
5. In general, the structure responded in a brittle type of failure mode, which is characteristic of low ductility.

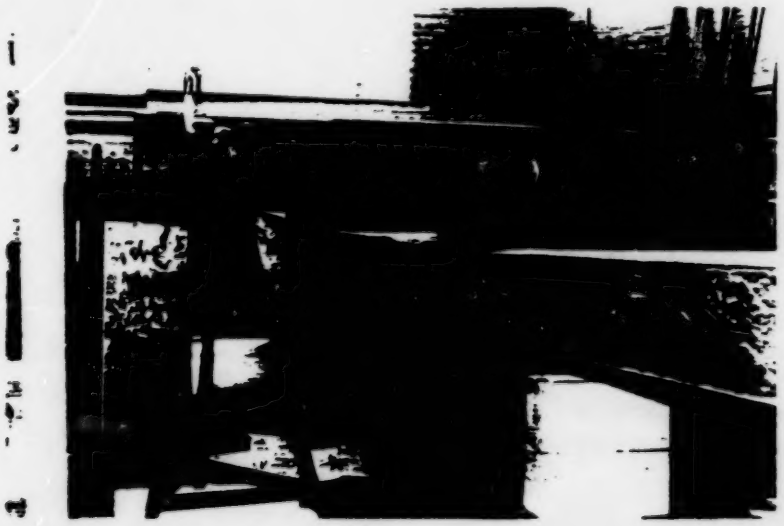


Figure 3.1 Joint Failure of the Specimen with the Applied Load Value of 123.5 lb/ft^2

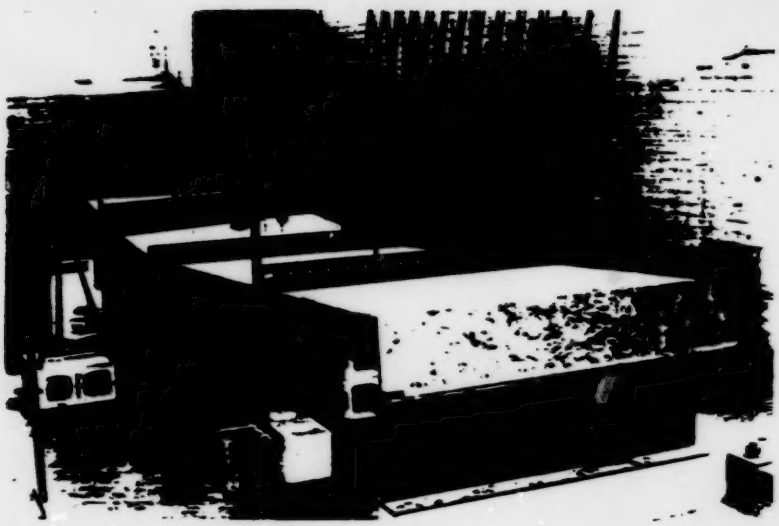


Figure 3.2 Failure Condition of the Specimen at Ultimate Applied Load Value of 145.9 lb/ft

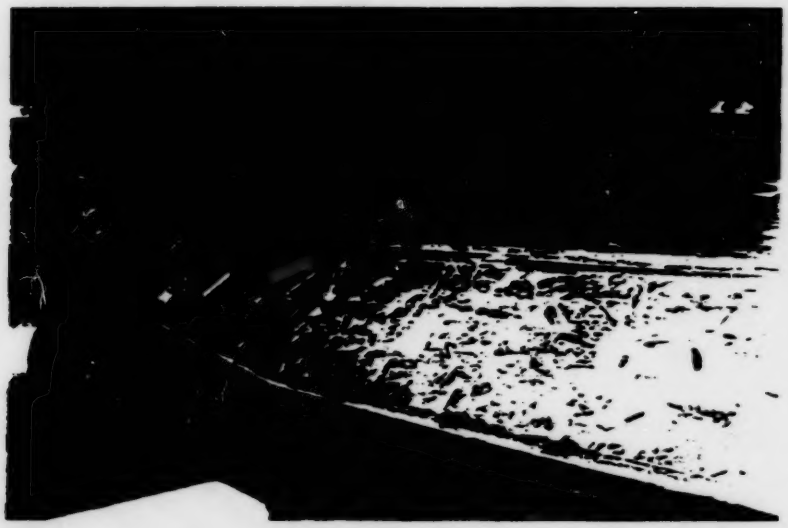


Figure 3.3 Failure Web Crack Formation at the Midspan at Ultimate Applied Load